



Queensland University of Technology

**DISCUSSION PAPERS IN ECONOMICS, FINANCE
AND INTERNATIONAL COMPETITIVENESS**

International SVAR Factor Modelling

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ISSN 1324-5910

Discussion Paper No. 109, April 2002

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INTERNATIONAL SVAR FACTOR MODELLING

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February 2002

Abstract

Models of Australia proxy international linkages using the US, despite Japan being an equivalent trading partner. This paper uses a Kalman filter to extract US and Japanese reference cycles which are then used in an SVAR model of the Australian economy. The US and Japanese shocks are interpreted to be aggregate demand and interest rate shocks respectively. The results show that US shocks are dominant for Australian outcomes, but the model is misspecified if Japan is excluded. The role of Japan is to dampen expansionary US shocks. Further, Australian monetary policy responds to domestic conditions, rather than international monetary policy.

Keywords

Structural VAR, latent factors, Kalman filter.

JEL Classifications: C51, E32, C82.

Introduction

Current macroeconometric and financial market modelling practices recognise the importance of specifying Australia as a small open economy. Recent work incorporating international influences in the Australian context include Bryan and Rafferty (1999), Henry and Summers (2000) and Kim and Sheen (2000). The Reserve Bank of Australia (RBA) also has an active history in the area; see the research discussion papers by Russell and de Roos (1996), de Brouwer and O'Reagan (1997), and Beechey, Bharucha, Cagliarini, Gruen and Thompson (2000), for some examples. Although these works discuss a range of influences, the empirical literature traditionally represents the international economy in models of Australia using either just US variables, or some aggregate measure of the world economy, such as OECD output; see de Brouwer and O'Reagan (1997) and Summers (1999).

Australia has significant international relationships with countries other than the US. In particular, Australia has a trading relationship with Japan that is similar in magnitude to that of the US.ⁱ However, extending current Australian macroeconometric models to incorporate additional trading partners is constrained by the rapid increase in the number of parameters required with each additional economy. Nevertheless, it is desirable to examine as many linkages as possible, as model misspecification problems may arise if significant linkages are omitted.

* This paper is based on my PhD thesis submitted to the University of Melbourne. I would like to thank Ron Bewley, Mardi Dungey, Stan Hurn, Vance Martin, Adrian Pagan and participants at the PhD Conference in Economics and Business (2001), The University of Western Australia, for their helpful comments.

This paper circumvents the overparameterisation problem by estimating latent factors for the US and Japanese economies, which are then included in an SVAR model for Australia. The approach is to use a Kalman filter to extract the commonality in the movements of the key macroeconomic series for the US and Japan into national latent factors for the two countries. These latent factors represent the state of each economy which are equivalent to Burns and Mitchell (1946) reference cycles. The approach also has much in common with the early business cycle models of Stock and Watson (1991) where the Kalman filter is used to extract the business cycle latent factor; see also Gerlach, and Klock (1988), Gregory, Head and Raynauld (1997) Kose, Ortrok and Whiteman (1999), Norrbin and Schlaganhauf (1996) and Pesaran, Schermann and Weiner (2001). The major difference between the current paper and these previous studies is that a casual structure between economies is imposed on the model through block exogeneity restrictions, whereby commodity prices influence all economies, the US factor influences the Japanese factor, and both the US and Japanese factors enter into selected sectoral equations of the Australian module. Australia as a small open economy does not influence any of the international variables in the model. An important advantage of this framework is that it is possible to identify how overall shocks in the US and Japanese economies transmit to Australia through their inclusion in the Australian component of the international SVAR model.

Various methods apart from the dynamic latent factor approach have been developed to measure the business cycle in the 45 years since the seminal work of Burns and Mitchell's (1946). Traditionally, the business cycle is measured by an index of coincident economic indicators; see Boehm and Moore (1984) for an overview of the construction of the Westpac-Melbourne Institute index for Australia. Another common method is the use of a single time series such as GDP to proxy the business cycle; see Artis, Kontolemis and Osborne (1997), Hess and Iwata (1997) and Harding and Pagan (1999). The disadvantage of using GDP as a proxy for the business cycle is that it only captures one element of the economy, not several like the factors derived in this paper; see also Boehm (1998) and Mintz (1972). The Hamilton (1989) regime switching model is also popular in business cycle analysis, where observed economic series are modelled to depend on an unobserved Markovian state variable; see Ghysels (1994) and Durland and McCurdy (1994) for some examples and extensions.

The key results from the impulse response analysis of the model include that a US factor shock, which is equivalent to an aggregate demand shock, leads to a strong Australian economy in conjunction with a depreciating exchange rate, an outcome which is similar to economic conditions experienced by Australia in 2000. Further, Australian monetary policy does not respond directly to an international monetary policy shock. An increase in international interest rates has a contractionary effect on Australian output, which is followed by an offsetting reduction in Australian interest rates. In line with statements by the RBA, this result implies that Australian monetary policy responds to domestic economic conditions, rather than the monetary policy decisions of major trading partners; see Fraser (1995). Formal testing indicates the importance of accounting for Japan in conjunction with the US in models for Australia. The inclusion of the Japanese reference cycle moderates the amplitude of the impulse response functions for the response of Australian variables to a US reference cycle shock due to the offsetting contractionary impact that the Japanese reference cycle has on the Australian economy.

The rest of this paper proceeds as follows. Section 2 presents an overview of the data. The specification of each of the modules of the US, Japanese and Australian economies is examined in Section 3. Particular attention is devoted to specifying the linkages between the reference cycles of the US and Japan, and the Australian SVAR. The estimation methodology is outlined in Section 4, followed by the empirical results in Section 5. Section 6 concludes.

Data

The reference cycles for the US and Japan are derived from a selection of key macroeconomic variables for each country. The key variables are output, inflation and the short term interest rate in each case, whilst the reference cycle for Japan also includes the US/Yen exchange rate. An exchange rate variable is not included for the US, as it is taken as the numeraire currency. The factors for the US and Japan represent the international economy in an Australian SVAR model. The SVAR model of Australia also includes Australian variables which represent demand, output, inflation, an interest rate and an exchange rate. The structure of the Australian module is discussed in Section 3.4. The commodity price index also enters the system, as commodity prices are traditionally included in VAR and SVAR models to capture inflationary expectations, or to represent the terms of trade in Australian models; see Sims (1992), Dungey and Pagan (2000) and Brischetto and Voss (1999). The variables of the international SVAR factor model, along with the abbreviations adopted in this paper, are summarised in Table 1.

Table 1: Definitions and abbreviations of key variables.

Variable	Definition ^(a)	Abbreviation
Commodity Prices	World commodity price index, logs	PC
US		
Output	GDP (SA), logs	GDP _U
Inflation	Inflation (SA), percent	INF _U
Interest Rate	Federal funds rate, percent	R _U
Japan		
Output	Industrial production (SA), logs	IP _J
Inflation	Inflation, percent	INF _J
Interest Rate	Call rate, percent	R _J
Exchange Rate	USD/Yen exchange rate, logs	E _J
Australia		
Demand	GNE, SA, logs	GNE _A
Output (SA)	GDP, SA, logs	GDP _A
Inflation	Inflation, percent	INF _A
Interest Rate	Cash rate, percent	R _A
Exchange Rate	Nominal trade weighted index	E _A

^(a) all data is detrended

The sample period begins September 1979, and ends December 1998. The level of each variable is expressed in natural logarithms with the exceptions of the interest rates and the inflation rates for each country, which are expressed in percentage terms. Data sources and codes are contained in Appendix A. All variables are detrended by regressing each variable against a constant and a

linear time trend and using the residuals as the detrended series. The use of detrended data implies that the reference cycle referred extracted by the Kalman filter is in growth cycle terms, as opposed to the cycle in the levels of the data; see Pagan (1997) and Boehm and Moore (1984). The model can be thought of as describing the dynamics around a steady state; see Dungey and Pagan (2000) for a similar approach.ⁱⁱ The use of detrended data is consistent with Lucas's (1977) definition of the business cycles as deviations of aggregate real output from trend. As there is no consensus on the most appropriate method of detrending, the simplest method of using the residuals from a regression of a series against a constant and a linear time trend is used in this paper; see Canova (1999), Canova and Marrinan (1998), Pagan (1997) and Burnside (1998). Two dummy variables are included in the exchange rate equation to allow for two outliers.ⁱⁱⁱ To overcome scaling problems, each detrended series is scaled by its own standard deviation, thereby expressing each series in standardized units.

Model Specification

Following the Stock and Watson (1991) approach, this paper extracts latent factors to represent the 'state of the economy' for the US and Japan. These are not directly interpretable as a measure of the business cycle as in the Burns and Mitchell (1946) tradition, as it is unlikely that all elements of the business cycle are captured by the macroeconomic series considered here. Rather, the factor for each economy represents Burns and Mitchell's reference cycle for the selected country specific macroeconomic aggregates. The approach adopted here is to consider the impact of commodity prices, the US latent factor and the Japanese latent factor on Australia. The effects of aggregate international shocks on Australia can be analysed in this framework.^{iv}

The international SVAR factor model can be decomposed into four modules. These are a commodity price module, a US factor module, a Japanese factor module and an Australian SVAR module. The main restriction imposed is that of block exogeneity between the modules in both the contemporaneous and dynamic structures of the model. Commodity prices are determined exogenously. As a large open economy, the US is an 'anchor' for the system, making it block exogenous to both Japan and Australia. Selover (1997) and Horiye, Naniwa and Ishihara (1987) support the transfer of the US business cycle to Japan, whilst Selover (1997) refutes the opposite direction. Similarly, the placement of Japan in the centre of the system is consistent with evidence that shocks from Japan are transmitted to Australia, but not vice-versa; see Selover and Round (1996). The Japanese economy is influenced by the US economy, but is block exogenous to the Australian economy. As a small open economy, Australia does not feedback into either the US or Japanese economies. These block exogeneity restrictions have become relatively common in two country open economy SVAR models recently, following the work of Cushman and Zha (1997).

The model is effectively ordered as world commodity prices (PC_t), the US factor ($f_{u,t}$), the Japanese factor ($f_{j,t}$), and the Australian variables. Each module is specified explicitly in this section.

Commodity Price Module

Commodity prices (PC) are exogenous to all economies and follow a second order scheme

$$PC_t = \mathbf{b}_1 PC_{t-1} + \mathbf{b}_2 PC_{t-2} + \mathbf{e}_{PC,t}, \quad (1)$$

where $\mathbf{e}_{PC,t}$ is a white noise process with zero mean and constant variance.

US Module

The US module of the international SVAR factor model is given in (2) and (3)

$$Y_{U,t} = A_U' PC_t + I_U' F_{U,t} + w_{U,t}, \quad (2)$$

$$F_{U,t+1} = \mathbf{f}_U F_{U,t} + v_{U,t+1} \quad (3)$$

Equation (2) gives the relationship between the vector of US variables $Y_{u,t}$, the matrix of factors $F_{u,t}$, and commodity prices PC_t . The matrices in (2) are explicitly specified for the US as follows

$$Y_{U,t}' = [GDP_{U,t} \ INF_{U,t} \ R_{U,t}], \quad (4)$$

$$A_U = [\mathbf{g}_{GDP_U} \ \mathbf{g}_{INF_U} \ \mathbf{I}_{R_U}], \quad (5)$$

$$F_{U,t}' = [f_{U,t} \ f_{U,t-1} \ u_{GDP_{U,t}} \ u_{INF_{U,t}} \ u_{R_{U,t}}], \quad (6)$$

$$I_U' = \begin{bmatrix} \mathbf{I}_{GDP_U} & 0 & \mathbf{s}_{GDP_U} & 0 & 0 \\ \mathbf{I}_{INF_U} & 0 & 0 & \mathbf{s}_{INF_U} & 0 \\ \mathbf{I}_{R_U} & 0 & 0 & 0 & \mathbf{s}_{R_U} \end{bmatrix} \quad (7)$$

The factor common to all US variables, $f_{U,t}$ in (6), is assumed to follow a second order scheme

$$f_{U,t} = \mathbf{f}_{U,1} f_{U,t-1} + \mathbf{f}_{U,2} f_{U,t-2} + \mathbf{h}_{U,t}, \quad (8)$$

whilst the idiosyncratic component of each equation, $u_{i,t}$, where $i = GDP_U, INF_U, R_U$, in (6) is assumed to follow a first order scheme. Commodity prices enter each US variable contemporaneously with loading parameters given in A_U' . The inclusion of an observable variable in the estimation of a factor is supported by Norrbin and Schlagenhauf (1996) who include changes in oil prices in their factor model. The matrices representing the state equation for the US in (3) are

$$\mathbf{f}_U = \begin{bmatrix} \mathbf{f}_{U,1} & \mathbf{f}_{U,2} & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & \mathbf{d}_{GDP_U} & 0 & 0 \\ 0 & 0 & 0 & \mathbf{d}_{INF_U} & 0 \\ 0 & 0 & 0 & 0 & \mathbf{d}_{R_U} \end{bmatrix}, \quad (9)$$

$$\mathbf{v}_{U,t}' = [\mathbf{h}_{U,t} \quad 0 \quad v_{GDP_{U,t}} \quad v_{INF_{U,t}} \quad v_{R_{U,t}}] \quad (10)$$

The error terms of the model $\mathbf{v}_{U,t}$ and $\mathbf{w}_{U,t}$ are *iid* $N(0,1)$ vector white noise processes, such that

$$E_U(v_{U,t}v_{U,t}') = \begin{cases} Q_U & \text{for } t = t \\ 0 & \text{otherwise,} \end{cases} \quad (11)$$

and

$$E_U(w_{U,t}w_{U,t}') = \begin{cases} R_U & \text{for } t = t \\ 0 & \text{otherwise} \end{cases} \quad (12)$$

Japanese Module

The Japanese component of the model is given by

$$Y_{J,t} = A_J' PC_t + \mathbf{I}_J' F_{J,t} + w_{J,t}, \quad (13)$$

$$F_{J,t+1} = \mathbf{f}_J F_{J,t} + v_{J,t+1}. \quad (14)$$

Equation (13) gives the relationship between the vector of Japanese variables $Y_{j,t}$, with the US and Japanese factors contained in $F_{j,t}$ with loading parameters \mathbf{I}_J' , and commodity prices with loading parameters A_J' . The relevant matrices for (13) are specified as

$$Y_{J,t}' = [IP_{J,t} \quad INF_{J,t} \quad R_{J,t} \quad E_{J,t}] \quad (15)$$

$$A_{J,t} = [\mathbf{g}_{IP_J} \quad \mathbf{g}_{INF_J} \quad \mathbf{g}_{R_J} \quad \mathbf{g}_{E_J}] \quad (16)$$

$$\mathbf{I}_J' = \begin{bmatrix} \mathbf{I}_{IP_J} & 0 & \mathbf{w}_{IP_J} & 0 & \mathbf{s}_{IP_J} & 0 & 0 & 0 \\ \mathbf{I}_{INF_J} & 0 & \mathbf{w}_{INF_J} & 0 & 0 & \mathbf{s}_{INF_J} & 0 & 0 \\ \mathbf{I}_{R_J} & 0 & \mathbf{w}_{R_J} & 0 & 0 & 0 & \mathbf{s}_{R_J} & 0 \\ \mathbf{I}_{E_J} & 0 & \mathbf{w}_{E_J} & 0 & 0 & 0 & 0 & \mathbf{s}_{E_J} \end{bmatrix}, \quad (17)$$

$$F'_{J,t} = \begin{bmatrix} f_{J,t} & f_{J,t-1} & f_{U,t} & f_{U,t-1} & u_{IP_{J,t}} & u_{INF_{J,t}} & u_{R_{J,t}} & u_{E_{J,t}} \end{bmatrix} \quad (18)$$

The idiosyncratic error for each equation, $u_{j,t}$, where $j = IP_J, INF_J, R_J, E_J$, in (18) is assumed to follow a first order scheme.

The matrices for (14) are

$$f_J = \begin{bmatrix} f_{J,1} & f_{J,2} & j_{J,1} & j_{J,2} & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & d_{IP_J} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & d_{INF_J} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & d_{R_J} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & d_{E_J} \end{bmatrix}, \quad (19)$$

and

$$v_{J,t} = \begin{bmatrix} h_{J,t} & 0 & v_{IP_{J,t}} & v_{INF_{J,t}} & v_{R_{J,t}} & v_{E_{J,t}} \end{bmatrix} \quad (20)$$

The US factor affects each Japanese variable as specified in (13), and also affects the Japanese factor directly with parameters $\Psi_{J,1}$ and $\Psi_{J,2}$, in line with the large economy assumption of the US. The Japanese factor is assumed to follow a second order scheme with error η_{jt} , and the matrices of error terms ω_{it} and $v_{j,t}$ are assumed to be *iid* $N(0, 1)$ with the same properties as for the US in (11) and (12).

Australian Module

The specification of the Australian SVAR component of the international model is similar to Dungey and Pagan (2000) and Dungey and Fry (2001), with the exception that the US and Japanese variables are replaced by their respective factors. The international linkages of the current paper are modelled through the US and Japanese factors entering the Australian output and exchange rate equations, as well as the commodity price variable which enters the Australian inflation rate and interest rate equations. A summary of the key relationships for each variable is given by,

$$GNE_{A,t} = f_1(GNE_{A,t-1}, GNE_{A,t-2}, GDP_{A,t-1}, GDP_{A,t-2}, INF_{A,t-1}, INF_{A,t-2}, R_{A,t-2}, E_{A,t-1}, E_{A,t-2}), \quad (21)$$

$$\begin{aligned}
GDP_{A,t} = f_2(f_{U,t}, f_{U,t-1}, f_{U,t-2}, f_{J,t}, f_{J,t-1}, f_{J,t-2}, \\
GNE_{A,t}, GNE_{A,t-1}, GNE_{A,t-2}, GDP_{A,t-1}, GDP_{A,t-2}, \\
INF_{A,t-1}, INF_{A,t-2}, R_{A,t-2}, E_{A,t-1}, E_{A,t-2}),
\end{aligned} \tag{22}$$

$$INF_{A,t} = f_3(GNE_{A,t}, GNE_{A,t-1}, GNE_{A,t-2}, INF_{A,t-1}, INF_{A,t-2}, R_{A,t-2}, E_{A,t-1}, E_{A,t-2}), \tag{23}$$

$$\begin{aligned}
R_{A,t} = f_4(PC_{t-1}, PC_{t-2}, GNE_{A,t}, GNE_{A,t-1}, GNE_{A,t-2}, \\
INF_{A,t}, INF_{A,t-1}, INF_{A,t-2}, R_{A,t-1}, R_{A,t-2}),
\end{aligned} \tag{24}$$

and

$$\begin{aligned}
E_{A,t} = f_5(PC_t, PC_{t-1}, PC_{t-2}, f_{U,t}, f_{U,t-1}, f_{U,t-2}, f_{J,t}, f_{J,t-1}, f_{J,t-2}, \\
GNE_{A,t}, GNE_{A,t-1}, GNE_{A,t-2}, GDP_{A,t}, GDP_{A,t-1}, GDP_{A,t-2}, \\
INF_{A,t}, INF_{A,t-1}, INF_{A,t-2}, R_{A,t}, R_{A,t-1}, R_{A,t-2}, E_{A,t-1}, E_{A,t-2}),
\end{aligned} \tag{25}$$

For convenience, the contemporaneous and dynamic structure of the Australian component of the multi-country SVAR factor model is given in Table 2. The dependent variables are shown in the columns of the table, whilst the parameters for the explanatory variables to be estimated for each equation are indicated by α_i .

Estimation

The international SVAR factor model is estimated in two stages. First, the US and Japanese factors of equations (2) to (3) and (13) to (14) are jointly estimated by

Table 2: Structure of the Australian component of the factor SVAR.

Explanatory Variables	Dependent Variables				
	GNE _{A,t}	GDP _{A,t}	INF _{A,t}	R _{A,t}	E _{A,t}
Contemporaneous structure					
PC _t					α_{44}
f _{U,t}		α_{10}			α_{45}
f _{J,t}		α_{11}			α_{46}
GNE _{A,t}		α_{12}	α_{26}	α_{34}	α_{47}
GDP _{A,t}					α_{48}
INF _{A,t}				α_{35}	α_{49}
R _{A,t}					α_{50}
E _{A,t}					
AR(1) structure					
PC _{t-1}				α_{36}	α_{51}
f _{U,t-1}		α_{13}			α_{52}
f _{J,t-1}		α_{14}			α_{53}
GNE _{A,t-1}	α_1	α_{15}	α_{27}	α_{37}	α_{54}
GDP _{A,t-1}	α_2	α_{16}			α_{55}
INF _{A,t-1}	α_3	α_{17}	α_{28}	α_{38}	α_{56}
R _{A,t-1}				α_{39}	α_{57}
E _{A,t-1}	α_4	α_{18}	α_{29}		α_{58}
AR(2) structure					
PC _{t-2}				α_{40}	α_{59}
f _{U,t-2}		α_{19}			α_{60}
f _{J,t-2}		α_{20}			α_{61}
GNE _{A,t-2}	α_5	α_{21}	α_{30}	α_{41}	α_{62}
GDP _{A,t-2}	α_6	α_{22}			α_{63}
INF _{A,t-2}	α_7	α_{23}	α_{31}	α_{42}	α_{64}
R _{A,t-2}	α_8	α_{24}	α_{32}	α_{43}	α_{65}
E _{A,t-2}	α_9	α_{25}	α_{33}		α_{66}

α_i indicates parameter to be estimated.

by maximum likelihood using the Kalman filter algorithm; see for example, Harvey (1981), Harvey (1990), Hamilton (1994, Chapter 13) and Lutkepohl (1993, Chapter 13). Second the resulting factors are included in the estimation of a SVAR model for Australia.^v

The log of the likelihood for the estimation of the factors of the model is specified as

$$\ln L = \sum_{t=1}^T \ln g_U(Y_{U,t} | PC_t, \Omega_{U,t-1}) + \sum_{t=1}^T \ln g_J(Y_{J,t} | PC_t, \Omega_{U,t-1}, \Omega_{J,t-1}), \quad (26)$$

where

$$\Omega_{U,t-1} = (Y'_{U,t-1}, Y'_{U,t-2}, \dots, Y'_{U,1}, PC_{t-1}, PC_{t-2}, \dots, PC_1), \quad (27)$$

$$\Omega_{J,t-1} = (Y'_{J,t-1}, Y'_{J,t-2}, \dots, Y'_{J,1}), \quad (28)$$

and $g_{k,t}$ is a multivariate normal density for $k = U, J$, given by

$$g_k(Y_t | X_t, \Omega_{k,t-1}) = (2\pi)^{-N_k/2} |I'_k P_{k,t|t-1} I_k + R_k|^{-1/2} \times \exp \left\{ \frac{1}{2} (Y_{K,t} - A'_k X_{k,t} - I'_k F_{k,t|t-1})' (I'_k P_{k,t|t-1} I_k + R_k)^{-1} \times (Y_{k,t} - A'_k X_{k,t} - I'_k F_{k,t|t-1}) \right\} \quad (29)$$

for $t = 1, 2, \dots, T$. The functions $F_{k,t|t-1}$ and $P_{k,t|t-1}$ are respectively the conditional mean and conditional variance-covariances of the factor $F_{k,t}$, which are defined below in equation (37) and (38), and where N is the number of endogenous variables associated with each equation. For the US $N_U = 3$, whereas for Japan $N_J = 4$.

The Kalman filter algorithm is initialized with the unconditional mean and variance of the factor

$$F_{k,1|0} = E_k(F_{k,1}) = 0 \quad (30)$$

and

$$P_{k,1|0} = E_k\{[F_{k,1} - E_k(F_{k,1})][F_{k,1} - E_k(F_{k,1})]'\}, \quad (31)$$

respectively. Alternatively, this last expression can be rewritten as

$$vec(P_{k,1|0}) = [I_{r^2} - (F_k \otimes F_k)]^{-1} \bullet vec(Q_k), \quad (32)$$

where $r = N_U, N_J$.

The associated conditional mean and variance of $Y_{k,t}$ are given by respectively

$$\begin{aligned} Y_{k,t|t-1} &= E_k(Y_{k,t} | X_{k,t}, \Omega_{k,t-1}) \\ &= A'_k X_{k,t} + I'_k F_{k,t|t-1}, \end{aligned} \quad (33)$$

and

$$E_k[(Y_{k,t} - Y_{k,t|t-1})(Y_{k,t} - Y_{k,t|t-1})'] = I'_k P_{k,t|t-1} I_k + R_k \quad (34)$$

Given the observation of $Y_{k,t}$, $F_{k,t}$ is updated using

$$F_{k,t|t} = F_{k,t|t-1} + P_{k,t|t-1} \mathbf{I}_k (\mathbf{I}_k' P_{k,t|t-1} \mathbf{I}_k + R_k)^{-1} (Y_{k,t} - A_k' X_{k,t} - \mathbf{I}_k' F_{k,t|t-1}), \quad (35)$$

with the mean squared error associated with the updated projection

$$P_{k,t|t} = P_{k,t|t-1} - P_{k,t|t-1} \mathbf{I}_k (\mathbf{I}_k' P_{k,t|t-1} \mathbf{I}_k + R_k)^{-1} \mathbf{I}_k' P_{k,t|t-1}. \quad (36)$$

A new forecast of $F_{k,t+1}$ is then produced in (37) from (3) for the US, or (14) for Japan,

$$F_{k,t+1|t} = \mathbf{f}_k F_{k,t|t}, \quad (37)$$

where the mean squared error ($P_{k,t+1|t}$) associated with this forecast is

$$\begin{aligned} P_{k,t+1|t} &= E_k [(F_{k,t+1} - F_{k,t+1|t})(F_{k,t+1} - F_{k,t+1|t})'] \\ &= \mathbf{f}_k P_{k,t|t} \mathbf{f}_k' + Q_k \end{aligned} \quad (38)$$

The procedure MAXLIK in GAUSS is used to maximise the likelihood function in (26). The BFGS iterative gradient algorithm in MAXLIK is used with the derivatives computed numerically.

The Australian module is estimated by taking the US and Japanese factors as exogenously determined by the likelihood function in equation (26), and placing the factors into the SVAR model for Australia as outlined in Table 2. The factors cannot be estimated simultaneously with the SVAR component of the model, as the factor F_{ijt} cannot be determined until the data series are observed, thus precluding the incorporation of contemporaneous relationships between the factors and the Australian variables; see (35).

The SVAR for the Australian module of the model is compactly written as

$$B_0 Y_{A,t} = B_1 Y_{A,t-1} + B_2 Y_{A,t-2} + A_0 X_t + A_1 X_{t-1} + A_2 X_{t-2} + \mathbf{e}_t, \quad (39)$$

where

$$Y_{A,t}' = [GNE_{A,t} \quad GDP_{A,t} \quad INF_{A,t} \quad R_{A,t} \quad E_{A,t}], \quad (40)$$

and

$$X_t = [PC_t \quad f_{U,t} \quad f_{J,t}], \quad (41)$$

which are taken as the exogenous variables to the Australian module of the system, and \mathbf{e}_t is a multivariate white noise process with zero mean and constant diagonal variance-covariance

matrix, D . The parameter matrix B_0 , contains the contemporaneous parameters corresponding to the Australian variables, with unit diagonal elements and off diagonal terms given in the "contemporaneous structure" block in Table 2 which represents the contemporaneous relationships amongst Australian variables. The parameter matrices B_1 , and B_2 correspond to the lagged endogenous variables in the Australian module, as outlined in Table 2. The matrices A_0 , A_1 and A_2 contain the parameters corresponding to the exogenous variables in the Australian module, namely the US and Japanese factors and the commodity price index.

Estimates of the Australian SVAR proceeds by using (39) to solve for $Y_{A,t}$

$$Y_{A,t} = B_0^{-1} B_1 Y_{A,t-1} + B_0^{-1} B_2 Y_{A,t-2} + B_0^{-1} A_0 X_t + B_0^{-1} A_1 X_{t-1} + B_0^{-1} A_2 X_{t-2} + B_0^{-1} e_t, \quad (42)$$

or,

$$Y_{A,t} = \Phi_1 Y_{A,t-1} + \Phi_2 Y_{A,t-2} + \Lambda_0 X_t + \Lambda_1 X_{t-1} + \Lambda_2 X_{t-2} + u_t, \quad (43)$$

where

$$\Phi_i = B_0^{-1} B_i, \quad i = 1, 2, \quad (44)$$

$$\Lambda_i = B_0^{-1} A_i, \quad i = 0, 1, 2, \quad (45)$$

$$u_t = B_0^{-1} e_t. \quad (46)$$

The likelihood function at the t^{th} observation is defined as

$$\ln L_t = -\frac{1}{2} \ln (2\pi) - \frac{1}{2} \ln |B_0^{-1} D B_0^{-1'}| - \frac{1}{2} u_t' (B_0^{-1} D B_0^{-1'})^{-1} u_t. \quad (47)$$

For a sample of $t = 1, 2, \dots, T$ observations, the log of the likelihood function is given by

$$\ln L = \sum_{t=1}^T \ln L_t, \quad (48)$$

which is maximised using the procedure MAYLIK in GAUSS. The BFGS iterative gradient algorithm is used with derivatives computed numerically.

Empirical Results

US Factor

The US results in Table 3 show that the loadings of the US factor ($\lambda_{U,i}$) are fairly well evenly spread across the three US variables. The derived US factor is compared with the three US series in Figure 1. These results further show that the US factor is not clearly representative of any particular series. The signs of the estimated values of the loadings of the US factor in the

equations for the US variables imply that the reference cycle is indicative of US aggregate demand, as a positive shock in aggregate demand would simultaneously result in increases in US GDP, inflation and the interest rate.

Japanese Factor

Table 4 presents the results of the Japanese component of the model. The largest loading of the Japanese factor is in the interest rate equation. Figure 2 graphically presents the Japanese factor with the Japanese variables. This figure clearly shows that the Japanese factor is well aligned with the interest rate. The loadings of the Japanese factor in the output and exchange rate equations are not significant.

The US reference cycle is included in the specification of both the Japanese variables and the Japanese reference cycle. The loadings of the US factor in the Japanese output, inflation and interest rate equations are all positive. The US factor has a negative relationship with the US/Japanese exchange rate, indicating that a strengthening US economy leads to a depreciation of the Japanese currency relative to the US, although this relationship is not significant. The specification of the Japanese factor includes the US factor in line with the block exogeneity restrictions of the model. As the parameters of the lags of the US factor, $\mathbf{j}_{J,1}$, and $\mathbf{j}_{J,2}$ in Table 4, are not significant, whilst the parameters of both lags of the Japanese factor, as given by $\mathbf{f}_{J,1}$ and $\mathbf{f}_{J,2}$ in Table 4 are significant, this result suggests that the Japanese reference cycle is largely interpreted as the Japanese interest rate and is determined by the domestic Japanese economy rather than by international events. This result is in contrast to Becker, Finnerty and Kopecky (1995) who find that US information has a significant effect on Japanese interest rates.

Figure 1: Comparison of the US factor with the US data. US factor (solid line), US data (dashed line).

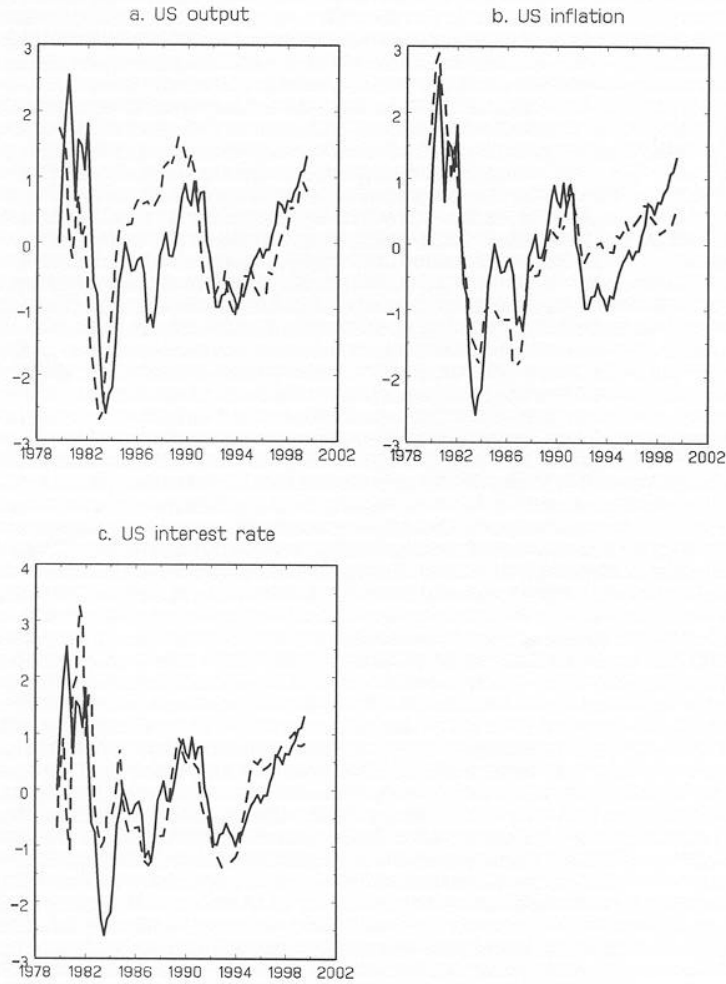


Figure 2: Comparison of the Japanese factor with the Japanese data. Japanese factor (solid line), Japanese series (dashed line).

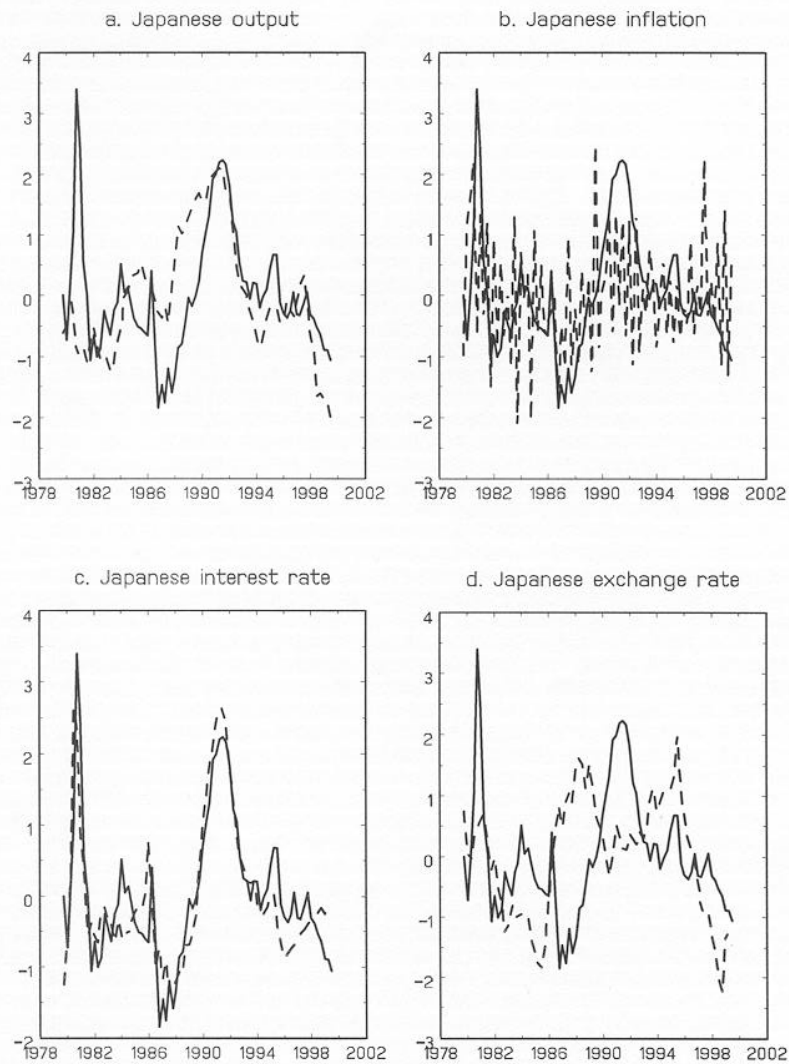


Table 3: US international SVAR factor model parameter estimates.

See (2) and (3). QMLE standard errors in brackets.

	Dependent variables (<i>i</i>)			
	GDP _{U,t}	INF _{U,t}	R _{U,t}	F _t ^(a)
$\lambda_{U,i}$	0.084 (0.082)	0.090 (0.046)	0.077 (0.070)	
$\sigma_{U,i}$	0.296 (0.071)	0.245 (0.055)	0.518 (0.105)	
$\delta_{U,i}$	0.947 (0.029)	0.906 (0.054)	0.753 (0.161)	
$\gamma_{U,i}$	0.162 (0.111)	0.057 (0.116)	0.203 (0.123)	
$\phi_{U,1}$				1.709 (0.282)
$\phi_{U,2}$				-0.764 (0.289)

^(a) The order of the factors in F_t and the corresponding parameter estimates are $F_t = \{f_{U,t-1}, f_{U,t-2}\}$.

Australian Empirical Results

The parameter estimates of the SVAR model for Australia are presented in Table 5. To highlight the properties of the SVAR factor model in the case of Australia, its VMA representation is derived. This is achieved by writing the full SVAR model as

$$B_0 Y_t = B_1 Y_{t-1} + B_2 Y_{t-2} + \mathbf{e}_t, \quad (49)$$

Table 4: Japanese international SVAR factor model parameter estimates.

See (13) and (14). QMLE standard errors in brackets.

	Dependent variables (<i>i</i>)				
	IP _{J,t}	INF _{J,t}	R _{J,t}	E _{J,t}	F _t ^(a)
λ _{J,i}	0.025 (0.038)	0.058 (0.021)	0.285 (0.123)	-0.007 (0.048)	
σ _{J,i}	0.250 (0.025)	0.669 (0.059)	0.148 (0.160)	0.342 (0.024)	
δ _{J,i}	1.019 (0.020)	-0.692 (0.074)	0.415 (0.713)	0.928 (0.041)	
γ _{J,i}	0.167 (0.081)	0.083 (0.092)	-0.412 (0.212)	0.215 (0.106)	
ω _{J,i}	0.040 (0.035)	0.035 (0.024)	0.044 (0.038)	-0.013 (0.022)	
ψ _{J,1}					0.127 (0.096)
ψ _{J,2}					-0.115 (0.084)
φ _{J,1}					1.395 (0.260)
φ _{J,2}					-0.514 (0.216)

^(a) The order of the factors in F_t and the corresponding parameter estimates are $F_t = \{f_{U,t-1}, f_{U,t-2}, f_{J,t-1}, f_{J,t-2}\}$.

Table 5: Australian international SVAR factor model parameter estimates.

See Table (2). QMLE standard errors in brackets.

Explanatory variables	Dependent variables				
	$GNE_{A,t}$	$GDP_{A,t}$	$INF_{A,t}$	$R_{A,t}$	$E_{A,t}$
Contemporaneous parameter estimates					
PC_t					-0.013 (0.137)
$f_{U,t}$		0.118 (0.073)			-0.173 (0.152)
$f_{J,t}$		-0.088 (0.063)			-0.008 (0.072)
$GNE_{A,t}$		0.699 (0.055)	0.122 (0.231)	0.142 (0.093)	-0.152 (0.155)
$GDP_{A,t}$					-0.124 (0.185)
$INF_{A,t}$				-0.028 (0.052)	-0.062 (0.052)
$R_{A,t}$					-0.196 (0.135)
$E_{A,t}$					
AR(1) parameter estimates					
PC_{t-1}				-0.081 (0.128)	-0.052 (0.185)
$f_{U,t-1}$		0.142 (0.094)			-0.072 (0.165)
$f_{J,t-1}$		0.044 (0.117)			-0.094 (0.118)
$GNE_{A,t-1}$	0.732 (0.179)	0.224 (0.143)	0.378 (0.259)	0.114 (0.120)	0.024 (0.159)
$GDP_{A,t-1}$	0.396 (0.226)	0.859 (0.191)			0.243 (0.191)
$INF_{A,t-1}$	0.004 (0.068)	-0.042 (0.057)	0.088 (0.172)	-0.038 (0.053)	-0.010 (0.049)
$R_{A,t-1}$				0.950 (0.105)	-0.164 (0.126)
$E_{A,t-1}$	0.072 (0.102)	-0.056 (0.085)	-0.367 (0.223)		0.653 (0.100)

continued overleaf

Table 5 continued

Explanatory variables	Dependent variables				
	GNE _{A,t}	GDP _{A,t}	INF _{A,t}	R _{A,t}	E _{A,t}
AR(2) parameter estimates					
PC _{t-2}				0.063 (0.118)	0.215 (0.120)
f _{U,t-2}		-0.058 (0.070)			0.165 (0.121)
f _{J,t-2}		-0.062 (0.082)			0.071 (0.100)
GNE _{A,t-2}	0.117 (0.178)	0.017 (0.168)	0.069 (0.337)	0.046 (0.123)	-0.057 (0.171)
GDP _{A,t-2}	-0.296 (0.200)	-0.357 (0.197)			-0.092 (0.187)
INF _{A,t-2}	-0.024 (0.048)	0.027 (0.042)	0.063 (0.091)	0.119 (0.048)	0.001 (0.057)
R _{A,t-2}	-0.127 (0.068)	-0.025 (0.062)	0.030 (0.119)	-0.197 (0.101)	0.077 (0.111)
E _{A,t-2}	-0.064 (0.108)	-0.036 (0.092)	0.099 (0.188)		0.152 (0.102)

where ε_t is a multivariate white noise process with zero mean and diagonal variance- covariance matrix D,

$$Y_t' = [PC_t \quad f_{U,t} \quad f_{J,t} \quad Y_{U,t} \quad Y_{J,t} \quad Y_{A,t}] \quad (50)$$

and $Y_{U,t}$, $Y_{J,t}$ and $Y_{A,t}$ are defined in (4), (15) and (40) respectively. The elements of the contemporaneous matrix, B_0 , and the dynamic matrices, B_1 , and B_2 , are constructed by extracting the parameters from the Kalman filter, the SVAR and the commodity price equations of the model and placing them in the appropriate B_0 , B_1 or B_2 matrices. Impulse response analysis can then continue in the traditional manner. The variance-covariance matrix is also constructed by extracting the appropriate parameter estimates.

To demonstrate the construction of the relevant matrices, the B_0 matrix is explicitly specified as follows as an example:^{vi}

Table 6: Standard deviations of the international SVAR factor model.

	US	Japan	Australia
f _{U,t}	1.000	f _{J,t} 1.000	GNE _{A,t} 0.400
GDP _{U,t}	0.295	IP _{J,t} 0.249	GDP _{A,t} 0.207
INF _{U,t}	0.245	INF _{J,t} 0.668	INF _{A,t} 0.864
R _{U,t}	0.517	R _{J,t} 0.148	R _{A,t} 0.345
		E _{J,t} 0.342	E _{A,t} 0.368
PC _t	0.350		

[illegible]

The size of each shock is given by the standard deviations of the variables as shown in Table 6. The following section investigates the impact of international shocks on the Australian macroeconomic variables. Two shocks are investigated. A US factor shock, and a shock in the Japanese factor. The relative contribution of the US and Japanese reference cycles to outcomes for Australia is then evaluated.

US Factor Shocks on Australia

A positive shock to the US factor implies simultaneous positive shocks in US output, inflation and the interest rate. As noted above, this suggests that a shock to the US factor can be interpreted as an aggregate demand shock in the US. The effects of a shock in the US factor on the Australian variables are presented in Figure 3. The impulse responses show that the US factor shock has a positive effect on Australian demand and output. This expansion in the Australian economy, in turn, has a positive effect on Australian inflation and interest rates. The exchange rate depreciates despite the stronger Australian economy, as the expansion in the US reference cycle is relatively larger than the expansion transmitted to the domestic Australian economy. It is of interest to note that these results are similar to economic conditions prevailing in 2000, when strong US output growth and strong Australian output growth were accompanied by a depreciation of the Australian currency.

Japanese Factor Shocks on Australia

The effects of a shock to the Japanese factor on the Australian economy are shown in Figure 4. As noted above, a positive shock to the Japanese factor can be interpreted as a shock to the Japanese interest rate. The results show that a shock to the Japanese factor results in a decline in

Australian demand and output. As the Australian economy contracts, the Australian interest rate falls, as does the inflation rate, whilst the domestic exchange rate depreciates.^{vii}

These results imply that monetary policy in Australia does not directly respond to innovations in the Japanese interest rate. The transmission of reference cycle shocks in Japan impact initially on Australian output and demand. Consistent with statements by the central bank, it is this subsequent contraction in the Australian economy that the RBA responds to, rather than international monetary policy condition; see Fraser (1995).

The relationship between the Australian economy and the Japanese interest rate is not well documented. Exceptions are Chinn (1994) and Rankel and Wei (1993), who evaluate the relative contributions of the Japanese and US interest rates on the Australian economy over the period 1982 to 1992. Both find that the US interest rate has a relatively greater impact than the Japanese interest rate on the Australian interest rate. More recent studies include Shan and Pappas (2000), and Fleming, Qing and Healy (2000). The latter study uses multivariate cointegration and error correction analysis to show that there are links between Australian and foreign interest rates, including the Japanese interest rate, once structural breaks are allowed for. In contrast to the approach of Fleming, Qing and Healy (2000), in the SVAR factor model presented in this paper, there is no direct relationship between the Japanese and Australian interest rates in this model.

Figure 3: Response of the US factor and Australian variables to a shock in the US factor.

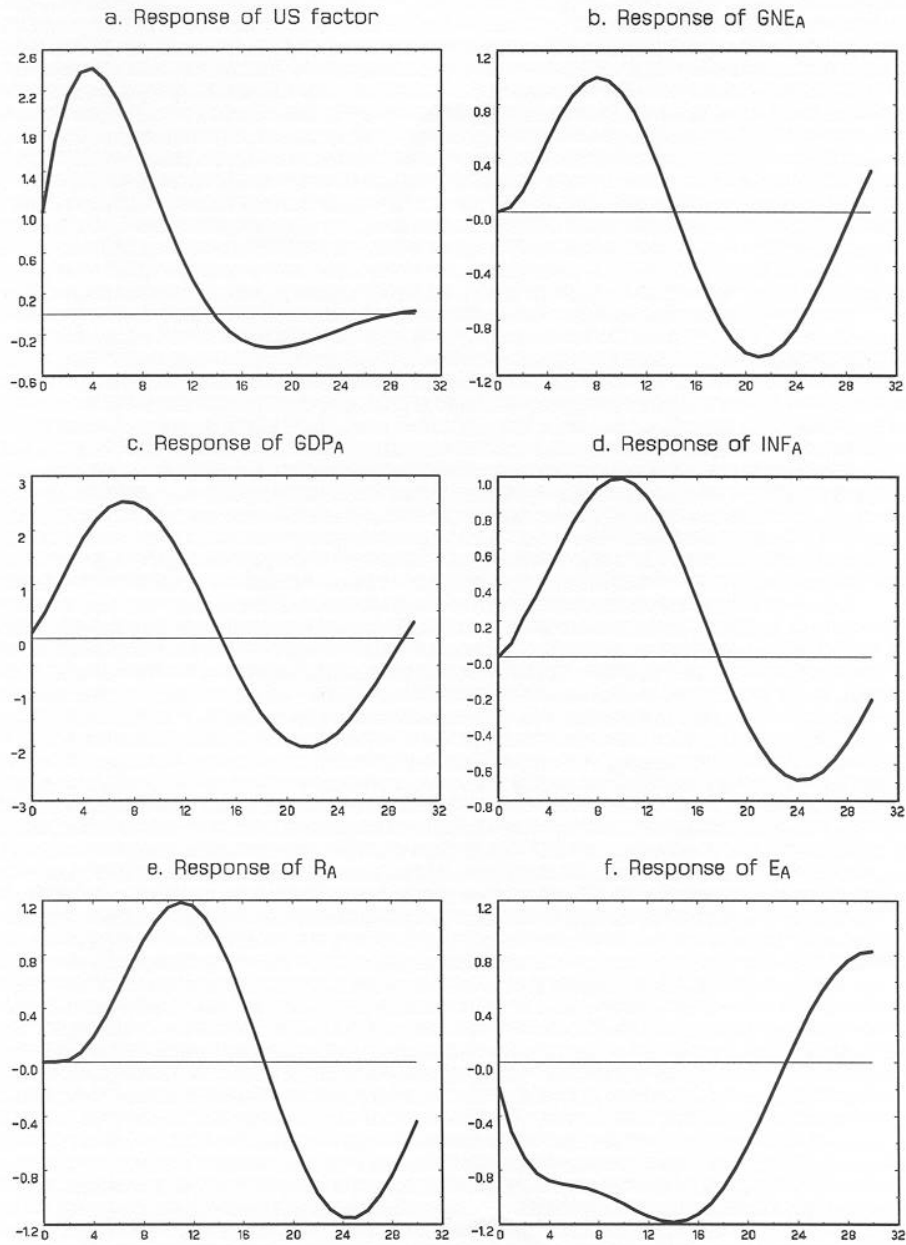
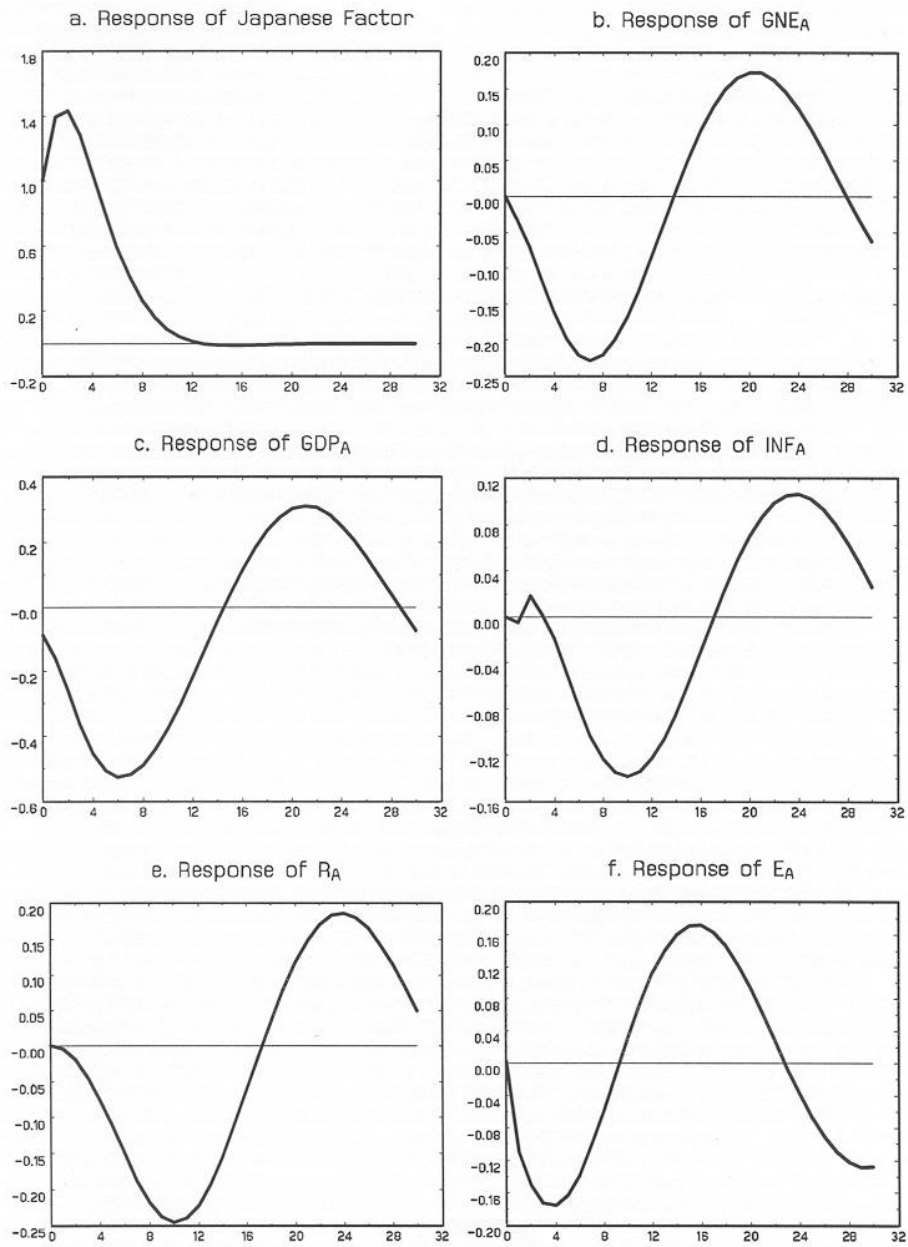


Figure 4: Response of Japanese factor and Australian variables to a shock in the Japanese factor.



Relative Contribution of US and Japanese Shocks on Australia

Despite the theoretically correct impulse response functions generated from a shock to the Japanese factor, none of the parameter estimates of the Japanese factor in the Australian equations represented in Table 5, are statistically significant. In contrast, the US factor is significant contemporaneously in the Australian output and exchange rate equations, although not significant elsewhere in the Australian module of the SVAR factor model.

The Australian responses to shocks to the US factor are augmented by their transmission through the Japanese factor. That is, a shock in the US will have direct effects on both Japan and Australia, as well as an indirect effect on Australia through the subsequent impact of the change in Japan on Australia. To decompose the effect of a US aggregate demand shock on Australia into the direct effect from the US and the indirect effect via Japan, the following procedure is adopted. First, the total effect of a shock to the US factor on Australia is obtained for the full model. Second, the causal linkages from Japan to Australia are set to zero whilst the remaining parameter estimates are based on the three country model results. The system is then shocked to yield the direct effect of a US sourced shock on Australia. The indirect effect of the US factor shock is given as the difference between the total and direct effects on the Australian variables.

Effectively, the decomposition of a US factor shock is a visual test of the following hypotheses. From Table 2, the first hypothesis is

$$H_0 : \mathbf{a}_{10} = \mathbf{a}_{13} = \mathbf{a}_{19} = \mathbf{a}_{45} = \mathbf{a}_{52} = \mathbf{a}_{60} = 0, \quad (51)$$

which is the direct effect of the US on Australia. The second hypothesis is

$$H_0 : \mathbf{a}_{11} = \mathbf{a}_{14} = \mathbf{a}_{20} = \mathbf{a}_{46} = \mathbf{a}_{53} = \mathbf{a}_{61} = 0, \quad (52)$$

which is the indirect effect of the US on Australia. The results in Figure 5 show that the majority of the impact of the US factor shock on Australia arises through direct effects. The inclusion of Japan moderates the amplitude of the impulse response functions due to the offsetting contractionary impact that the Japanese interest rate has on the Australian economy.

Formal tests of the joint significance of Japan and the US in the Australian component of the model are presented in Table 7. Three likelihood ratio tests are performed. The first and second tests are based on the null hypotheses in (51) and (52), whilst the third is a joint test of the total impact of the US on Australia, based on the following null hypothesis

$$\begin{aligned} H_0 : \mathbf{a}_{10} = \mathbf{a}_{13} = \mathbf{a}_{19} = \mathbf{a}_{45} = \mathbf{a}_{52} = \mathbf{a}_{60} = 0, \\ \mathbf{a}_{11} = \mathbf{a}_{14} = \mathbf{a}_{20} = \mathbf{a}_{46} = \mathbf{a}_{53} = \mathbf{a}_{61} = 0, \end{aligned} \quad (53)$$

The results of these tests indicate that at the 5% level of significance the US is jointly significant in Australia, at the 10% level of significance Japan is jointly significant in Australia, and at the 1% level of significance both the US and Japan are jointly significant in Australia. This result

indicates that to avoid model misspecification, Japan should not be excluded from an Australian SVAR model.

Conclusions

A fundamental problem in building macroeconometric models whilst accounting for the economic conditions of a variety of countries is the rapid increase in the number of parameters as the model is expanded to account for Australia's interrelationships with their trading partners. The approach adopted in this paper to circumvent overparameterisation problems was to specify factor models for the international economies and allow the dynamics between countries to be channelled through these factors. In specifying the international SVAR factor model, a causal ordering was imposed whereby commodity prices entered the US factor, which fed into the Japanese factor. In turn, commodity prices and the two national factors fed into selected sectoral equations of the Australian module. Further reductions in the number of parameters could be achieved by specifying a factor structure for the Australian module as well.^{viii}

The factors derived from the key data series for each of the international economies in the model were interpreted as a measure of a Burns and Mitchell (1946) reference cycle. The empirical results showed that a shock in the US factor could be interpreted as an aggregate demand shock whereas a shock to the Japanese factor represented an interest rate shock. The results for the US factor shock were similar to the economic conditions of the 2000, where strong US output growth and strong Australian output growth were accompanied by a depreciation of the Australian currency. The implications for an international monetary policy shock for Australian monetary policy were also assessed. The key result was that Australian monetary policy is formed in light of domestic economic conditions. An increase in the interest rates of a major trading partner does not imply that Australian interest rates will follow the upward movement. The impact of the Japanese interest rate shock on Australia is through the contractionary effect that the increase in the Japanese interest rate has on Australian output. Australian interest rates, in turn, respond to the reduction in Australian output by declining.

The results of this paper indicated that the SVAR model for Australia was misspecified if Japan was excluded. The omission of Japan was likely to result in an over compensation by Australian policy makers to US reference cycle shocks, as the inclusion of Japan in the model had an offsetting effect on the Australian module in response to an expansionary US economy.

Figure 5: Decomposition of direct and indirect effects of a US factor shock on the US factor, and Australian variables. Total US effect (solid line), direct effect of the US on Australian variables (dashed line), indirect effect via Japan (dotted line).

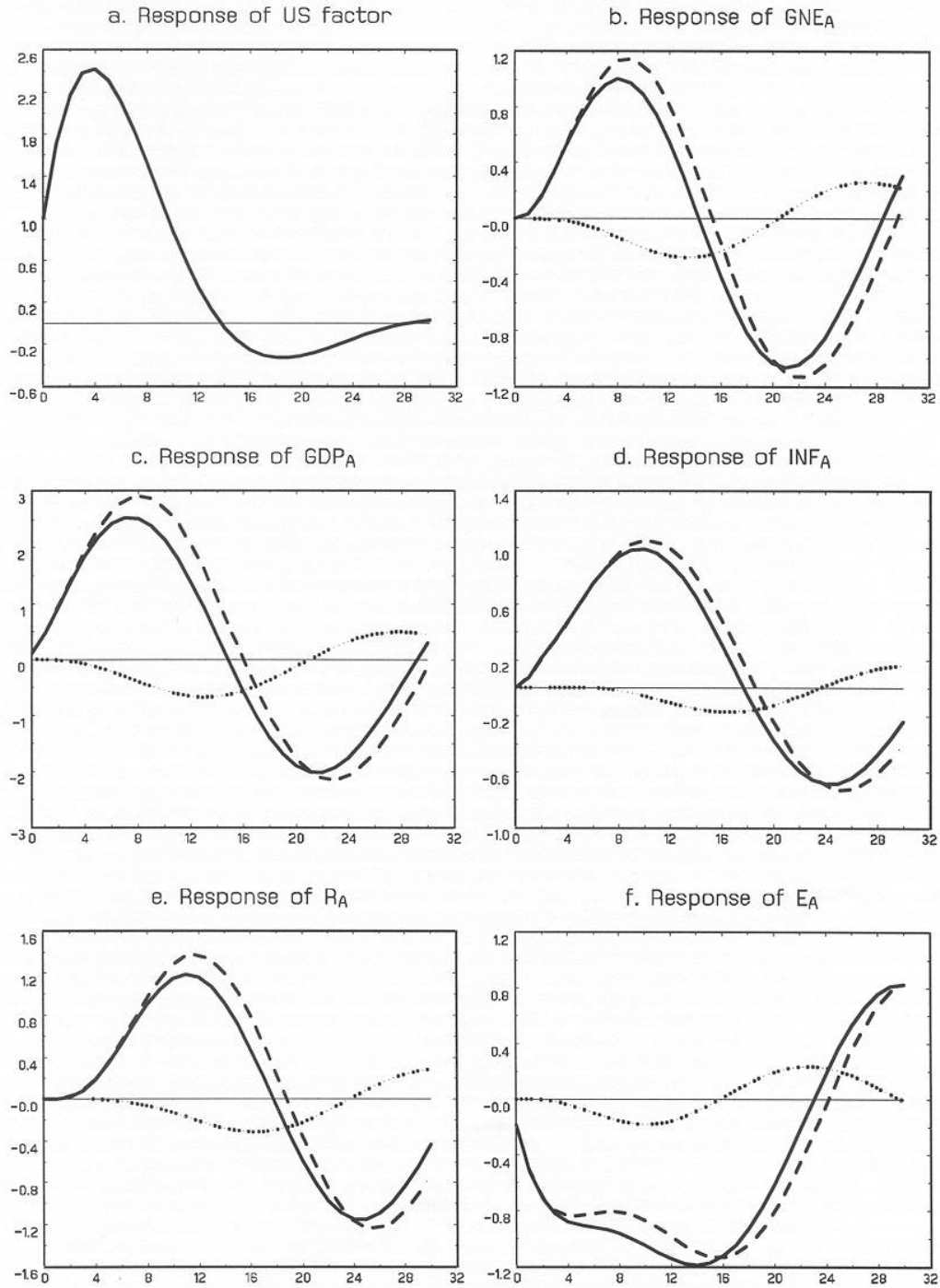


Table 7: Likelihood ratio tests of joint significance in Australia.

	Statistic	p-value
1. US in Australia (Direct effect)	15.779	0.015**
2. Japan in Australia (Indirect effect)	10.823	0.093*
3. US and Japan in Australia (Total effect)	19.349	0.004***
1. $H_0: \alpha_{10} = \alpha_{13} = \alpha_{19} = \alpha_{45} = \alpha_{52} = \alpha_{60} = 0$,		
2. $H_0: \alpha_{11} = \alpha_{14} = \alpha_{20} = \alpha_{46} = \alpha_{53} = \alpha_{61} = 0$,		
3. $H_0: \alpha_{10} = \alpha_{13} = \alpha_{19} = \alpha_{45} = \alpha_{52} = \alpha_{60} = 0$,		
$\alpha_{11} = \alpha_{14} = \alpha_{20} = \alpha_{46} = \alpha_{53} = \alpha_{61} = 0$.		
* denotes significance at the 0.10 level		
** denotes significance at the 0.05 level		
*** denotes significance at the 0.01 level		

Data Sources and Codes

Table 8: Data sources, codes and abbreviations.

Variable	Source	Code	Abbreviation
Commodity Price Index	Datastream	WDI76AXDF	PC
USA			
Real GDP (SA)	Datastream	USGDP...D	GDP_U
Inflation (SA)	Datastream	USI64...F	P_U
Federal Funds Rate	Datastream	USI60B..	R_U
Japan			
Industrial Production (SA)	Datastream	JPI66..IF	IP_J
Inflation	dX	IOEJPCPI	P_J
Call Rate	Datastream	JPI60..B	R_J
USD/YEN	dX		E_J
Australia			
GNE (SA)	Datastream	AUGNE...D	GNE_A
Real GDP (SA)	Datastream	AUGDP...D	GDP_A
Inflation	dX	GCPIAGU	P_A
Cash Rate	Datastream	AUCASH11F	R_A
Nominal Trade Weighted Index	dX	A8.119aH	E_A

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Endnotes

ⁱ Nearly 20% of Australia's exports go to Japan, whilst about 10% of Australia's exports go to the US. The US is the dominant source of imports for Australia, at almost 20% of total imports. Imports originating from Japan are also sizeable at around 13%. Source: Australian Bureau of Statistics (2001), Cat. No. 5432.0.65.001, Table 1 and Table 2, and Cat. No. 5439.0, Table 1 and Table 3.

ⁱⁱ An alternative approach to incorporating long run relationships in the model is to specify a cointegrating system following the SVAR model of the UK economy developed by Garratt, Lee, Pesaran and Shin (2001), and Pesaran, Schuermann and Weiner (2001).

ⁱⁱⁱ The first outlier occurs in June 1985, when the cash rate jumped 300 basis points. The second occurs in September 1986, to account for the effects of the Banana Republic statement made by the then Treasurer of Australia, Paul Keating; see Dungey and Pagan (2000).

^{iv} Metin (1995) presents an alternative approach to the one presented here by testing for, and including the cointegration relationships of a selection of variables in a model along with other explanatory variables to estimate inflation equations.

^v The factors $F_{t|t}$ are not the “smoothed” factors, namely $F_{t|T}$. The reason for this is in developing the SVAR factor model below, the focus of attention is on identifying the impact of contemporaneous shocks from the US and Japanese factors to Australia, a result which is not consistent with using $F_{t|T}$.

^{vi} B_1 and B_2 are constructed in a similar manner; see Fry (2001) for further details.

^{vii} The turning points and shapes of the impulse response functions from the model of this paper are close to the corresponding impulse responses generated from a fully parameterised SVAR version of this model in Dungey and Fry (2001). This suggests that little information is lost in aggregating the international economies into factors, whilst the overparameterisation problem of the larger model is alleviated.

^{viii} This model was pursued in Chapter 5 of Fry (2001).